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Armorcoat® Safety And Security Films

Explosive Blast Tests Per GSA Security Criteria

- Test Site:** Chestnut Test Site, Kirtland Air Force Base, New Mexico
Owned and Operated by Defense Threat Reduction Agency
- Conducted By:** Applied Research Associates, Inc.
Security Engineering Group
February 2000
- Summary:** A number of high explosive tests were conducted in an open air environment to determine the hazard mitigation value of **Bekaert Specialty Films, LLC's Armorcoat® safety and security window films** installed to commercially available windows with annealed glass. These films were tested with and without "anchoring" systems. The results demonstrated that glass filmed with **Armorcoat** provided significant hazard reduction with regard to flying glass due to explosive blast loads. **These Armorcoat films as manufactured by Bekaert Specialty Films, LLC, met the GSA Security Criteria for Level C buildings for the tested configuration. Certain tested films met the overpressure requirements of the Level D Buildings, but due to range restrictions were only tested to 60% of the impulse requirement.**



**APPLIED
RESEARCH
ASSOCIATES, INC.**

Engineering and Applied Science

November 3, 2001

Bekaert Specialty Films, LLC
Attn: Mr. Steve Hojnowski
4540 Viewridge Ave.
San Diego, CA 92123

Reference: Bekaert Letter Dated 10-12-2001

Subject: Name Change of Company

Dear Sir:

I have reviewed your letter dated October 12, 2001 related to the change in name of Material Sciences Corporation to Bekaert Specialty Films, LLC. As I understand your letter, Bekaert Specialty Films, LLC purchased the Specialty Films, Inc. division of Material Sciences Corporation. Applied Research Associates performed explosive tests on MSC film products in the Feb-March 2000 timeframe. The test report was produced under the company's name MSC Specialty Films at that time. The test results and conclusions in the test report should directly apply under your new name providing that the material production process and materials used remain the same as that tested.

We look forward to assisting you in the future under your new name.

Sincerely,

Joseph L. Smith
Vice President
Director, Security Consulting Services



Engineering and Applied Science

ARA-TR-00-0041.1-3

Explosive Tests For the Evaluation of the Glass Fragment Mitigation Characteristic of MSC Specialty Films Inc. Security Window Films

Prepared by:

**Joseph L. Smith, Director of Security Engineering
James T. Brokaw, Senior Blast/Security Engineer**

**Applied Research Associates, Inc.
Security Engineering Group
112 Monument Place
Vicksburg, MS 39180**

August 2000

Prepared for:

**MSC Specialty Films Inc.
4540 Viewridge Avenue
San Diego, CA 92123**

PREFACE

Applied Research Associates, Inc. (ARA) conducted high-explosive tests on February 15-March 3, 2000, in order to evaluate the response of security window film to blast loads. Five high explosive tests were conducted and four windows were evaluated in each test for a total of 20 window samples. This report documents the findings of these tests.

The tests were performed at the Chestnut Test Site on Kirtland Air Force Base in New Mexico. This test site is owned and operated by the Defense Threat Reduction Agency (DTRA), which is the US Government's lead agency for force protection. A special thanks is extended to DTRA for allowing ARA use of the test site. This work was sponsored by MSC Specialty Films Inc. The support and efforts of MSC Specialty Films Inc. are acknowledged and greatly appreciated

| NAME | TITLE | PROJECT ASSIGNMENT |
|------------------|--------------------------------------|---|
| James T. Brokaw | Senior Engineer | Principal investigator, field test engineer |
| Joseph L. Smith | Director, Security Engineering Group | Program oversight, technical review |
| Robert E. Walker | Principal Engineer | Technical review |
| Larry M. Bryant | Senior Engineer | Analysis |
| Charles Ellison | Staff Engineer | Analysis |
| Paul Gay | Engineering Aide | Analysis |
| Donald Cole | Principal Engineer | Test site oversight |
| Sue Babcock | Principal Engineer | Test conductor |
| Rob Cilke | Senior Engineer | Video analysis support |
| Manny Davilla | Technician | Photography |
| Jeff Gentry | Technician | Test bed setup |
| Lonnie Bamert | Technician | Explosives |

EXECUTIVE SUMMARY

In response to the heightened concern about terrorism, the US Government and private industry are developing and testing new technologies to mitigate hazards to people in the vicinity of a terrorist bombing. In cooperation with the Defense Threat Reduction Agency, Applied Research Associates conducted tests to assess the capability of security window film to reduce the hazards of flying glass shards during an explosion. Propelled by the forces of a terrorist bomb, glass fragments cause large numbers of serious injuries.

The US General Services Administration (GSA) developed criteria for evaluation of acceptable levels of protection from the glass fragment hazards in a terrorist bombing. These criteria are part of the comprehensive security criteria (GSA Security Criteria, Final Working Version, January 1997) developed by the GSA, which includes physical security, electronic security, and many other criteria for blast considerations. The GSA has indicated that manufacturers must test their window products against the criteria to evaluate the performance of these products in blast if they want to be considered for use in GSA buildings. The current GSA Test Procedure is included in Appendix A.

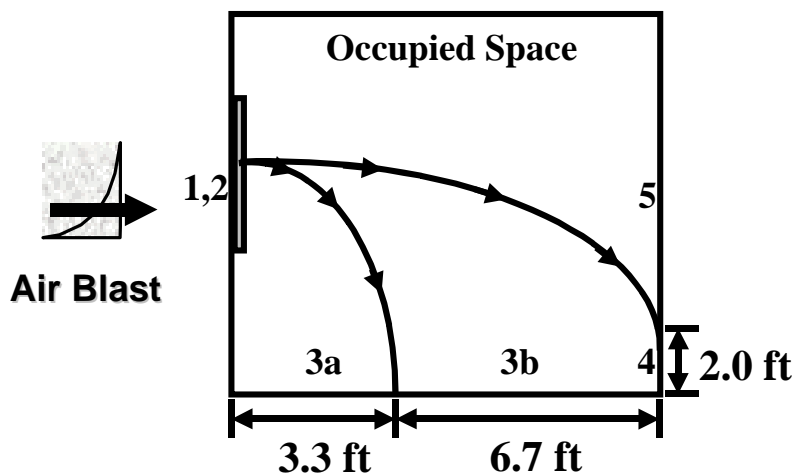
MSC Specialty Films Inc. commissioned ARA to perform a series of five open-air high explosive tests in order to evaluate the performance of security window film products. The tests were conducted from February 15 to March 3, 2000. Four windows were evaluated in each test for a total of 20 windows. The test data collected in this effort will provide useful information for many other government and civilian entities, both domestic and foreign, that are responsible for security planning of building facilities.

The test used the GSA protocol in Appendix A. The windows were mounted in enclosed concrete reaction structures. The response of each window was captured with high-speed film and still photography. An exterior high-speed camera and an exterior normal-speed video camera were used to capture the views of the structures and the explosive detonation for each test. The reaction structures were instrumented with pressure gages to measure the exterior reflected pressure on the specimens and the internal pressure in the structures.

The test charge was 600 lb of Ammonium Nitrate and Fuel Oil (ANFO), which is equivalent to 500 lb of TNT. The standoff distance to the structures was varied to affect specific peak pressures on the test specimens.

A thorough test matrix was developed to explore the effect of film thickness and attachment method on window response. The nominal window size for the tests was 4 ft by 5-1/2 ft. One-fourth inch thick annealed glass was used during testing. The windows were tested in commercially available aluminum storefront window frames. The glass type and film attachment method for each window is given in the summary and test description for each test.

The GSA glass fragment hazard rating scheme is presented graphically and is described in the table which follows. The approach compares potential hazards based on the type and location of glass fragments interior and exterior to the test cubicle. These criteria indirectly reflect the velocity (hence hazard level) of fragments based on their distance from the original window position.



| Performance Condition | Protection Level | Hazard Level | Description of Window Glazing Response |
|------------------------------|-------------------------|---------------------|--|
| 1 | Safe | None | Glazing does not break. No visible damage to glazing or frame. |
| 2 | Very High | None | Glazing cracks but is retained by the frame. Dusting or very small fragments near sill or on floor acceptable. |
| 3a | High | Very Low | Glazing cracks. Fragments enter space and land on floor no further than 3.3 ft. from the window. |
| 3b | High | Low | Glazing cracks. Fragments enter space and land on floor no further than 10 ft. from the window. |
| 4 | Medium | Medium | Glazing cracks. Fragments enter space and land on floor and impact a vertical witness panel at a distance of no more than 10 ft. from the window at a height no greater than 2 ft. above the floor. |
| 5 | Low | High | Glazing cracks and window system fails catastrophically. Fragments enter space impacting a vertical witness panel at a distance of no more than 10 ft. from the window at a height greater than 2 ft. above the floor. |

The results of the tests are documented in the following tables. MSC Specialty Films Inc. safety/security films provided significant reductions in glass fragment hazards versus unprotected windows. The films performed well at mitigating hazard in monolithic, 1/4 inch annealed glass window systems. Different film attachment methods performed to specified criteria for GSA Level C buildings up to a 4 psi (28 psi-msec) peak blast pressure. Thicker film with attachment system performed to a GSA performance condition 3 at 10 psi and 48 psi-msec.

RESULT SUMMARIES AND CONCLUSIONS

The GSA Security Criteria requires that windows meet a certain level of performance for a particular blast design threat. This is true for GSA buildings with security classifications of Levels C and D. Level A and Level B buildings, which are lower in security classification than C and D buildings, require no specific blast performance criteria though the use of certain window types in Level A and B buildings is prohibited. Level E buildings are very high security buildings and the generalized criteria do not give guidance for these buildings.

The airblast loading that is used in the window design for GSA Level C and Level D buildings is based on a particular threat size at the worst-case threat scenario location given the available perimeter standoff. Realistic limits are placed on the maximum design loads with the assumption that some damage and potential injury are acceptable. For Level C buildings, any portion of the building that is predicted to experience blast pressures of ½ psi or higher due to the design threat at the site perimeter must be designed up to the maximum predicted load. For Level D buildings, the design is to correspond to the actual predicted blast environment.

For GSA Level C Buildings the maximum required design blast load for windows is a triangular blast load that instantaneously rises to 4 psi and decays linearly to zero over a duration of 14 milliseconds (msec). The performance required for GSA Level C buildings is a Condition 4 or lower. The associated impulse requirement is 28 psi-msec. Thus, window specimens that performed to a Condition 4 or lower at 4 psi/28 psi-msec from this test series can be considered for use in GSA Level C Buildings. This is generally true for windows that are the size of those tested or smaller. Framing and anchorage conditions specific to a particular project must be addressed separately.

For GSA Level D buildings, the maximum required design load for windows is a triangular blast load that instantaneously rises to 10 psi and decays linearly to zero over a duration of about 17.9 msec (i.e., 89 psi-msec impulse). All windows that performed to a Condition 3 or better can be considered for use on Level D buildings up to the maximum pressure and impulse level at which they were tested. This is true for windows that are the size of those tested or smaller. Framing conditions specific to a particular project must be addressed separately.

Interagency Security Committee (ISC) Security Criteria are similar with minor modifications.

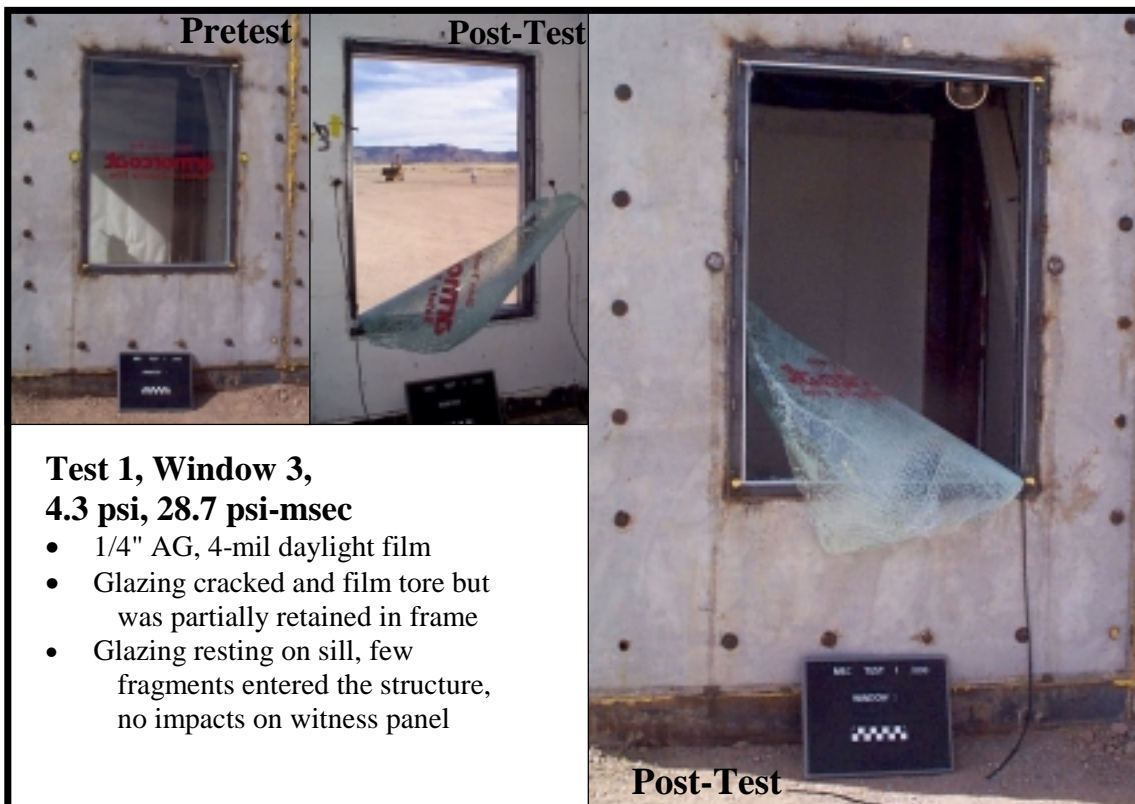
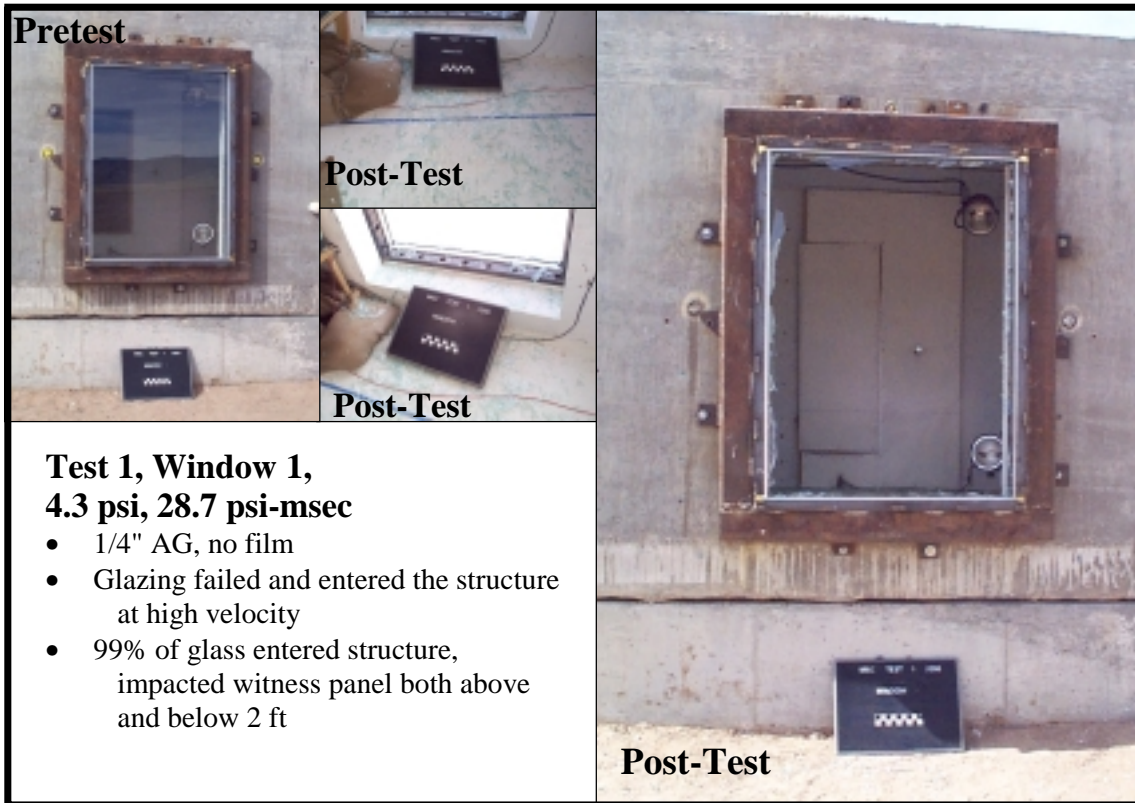
Result Summaries

Test windows were constructed with standard commercial aluminum frames and ¼ inch annealed glass. The windows were tested under conditions consistent with the “US General Services Administration (GSA) Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loading” (Appendix A). Twelve test articles were tested at GSA Performance Criteria for Level C buildings 4 psi (28 psi-msec). Eight test articles were tested at a higher pressure loading of 10 psi. The results for the test articles at 4 psi (28 psi-msec) are summarized in Table 4.1 through Table 4.3. The articles tested at 10 psi (48 psi-msec) are summarized in Table 4.4.

Table 4.1 presents results of test articles using daylight application of film when subject to airblast loading of 4 psi (28 psi-msec). Film was installed in a daylight application with a 1/16 inch or smaller gap between the edge of the window film and the window frame. Each of the following test articles with daylight application surpassed the GSA Performance Criteria requirements for Level C buildings (performance conditions 1 through 4 are acceptable).

| Peak Pressure (PSI) | Test Article | Film | Application Method | GSA Performance Condition |
|---------------------|--------------|--------------|--------------------|---------------------------|
| 4.3 | MSC-1-1 | No film | --- | 5 |
| 4.3 | MSC-1-3 | 4-mil | daylight | 3b |
| 4.3 | MSC-1-2 | 7-mil | daylight | 3b |
| 4.3 | MSC-1-4 | 8-mil, 2 ply | daylight | 3b |

Table 4.1 Summary of results for daylight installed film at 4-psi (28 psi-msec) pressure on ¼ inch annealed glass (46 × 64 inch window panes).



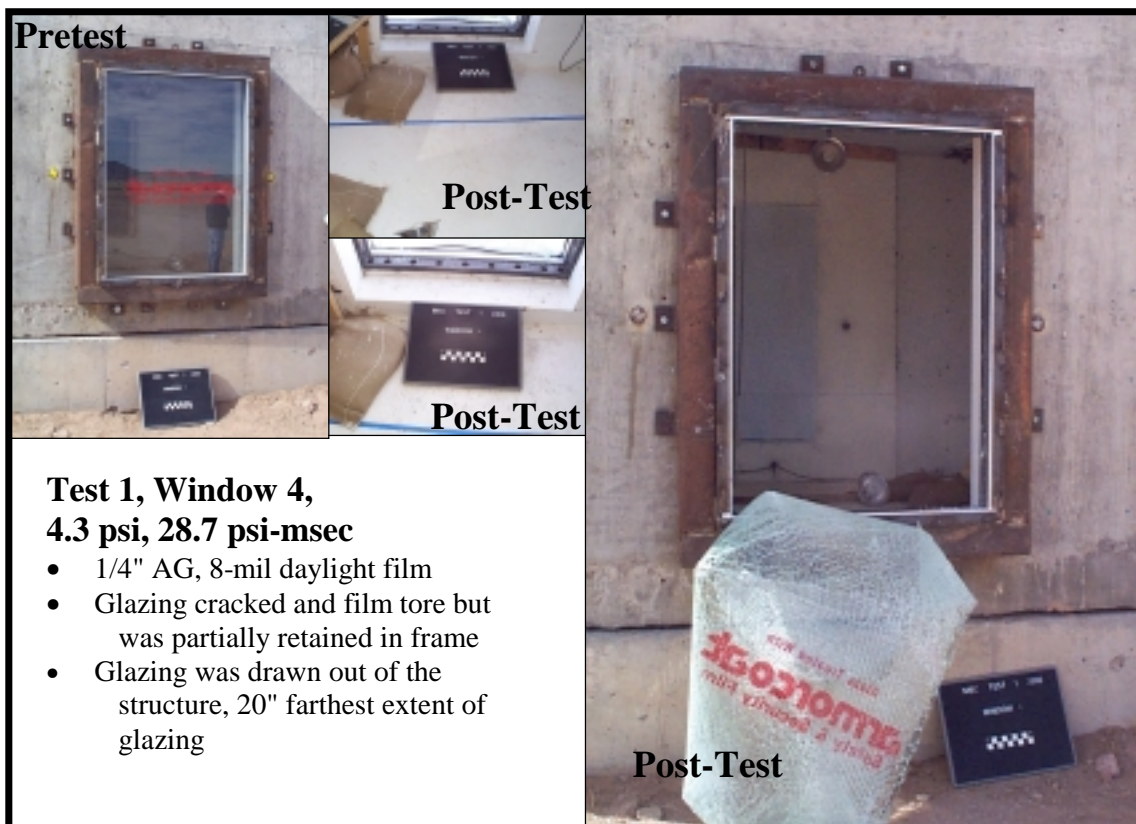
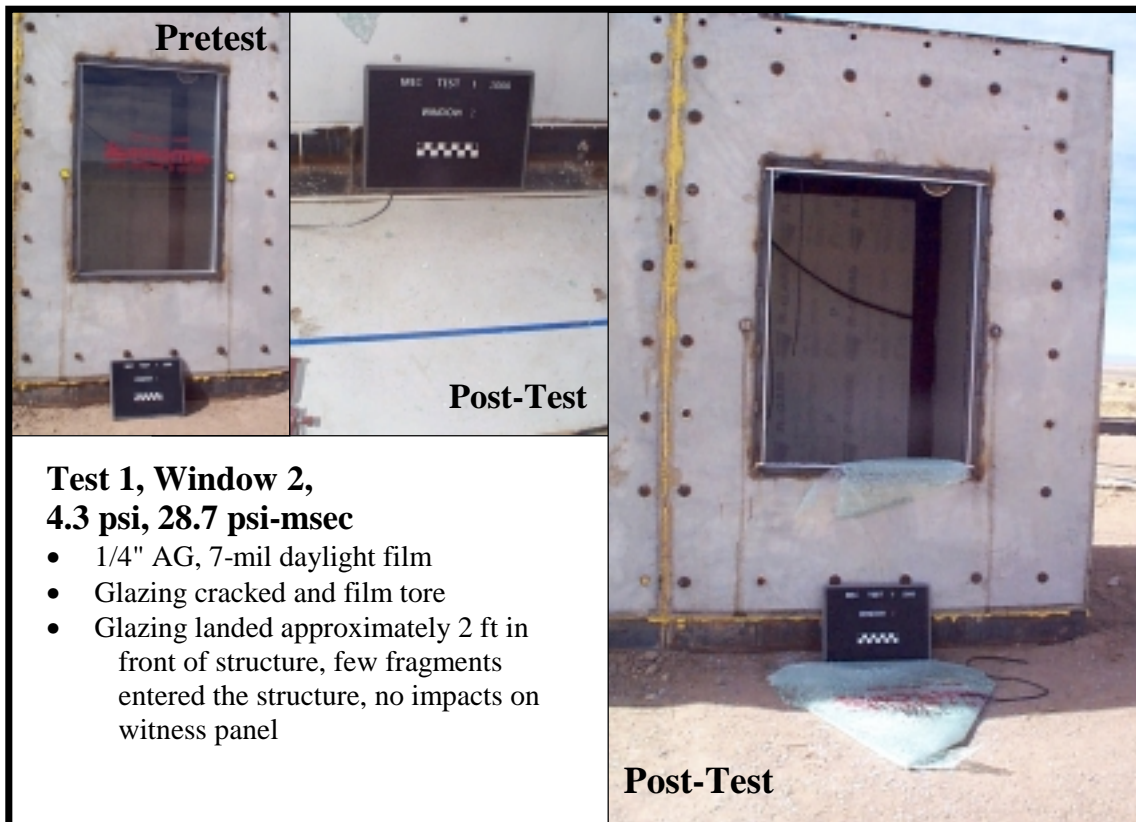
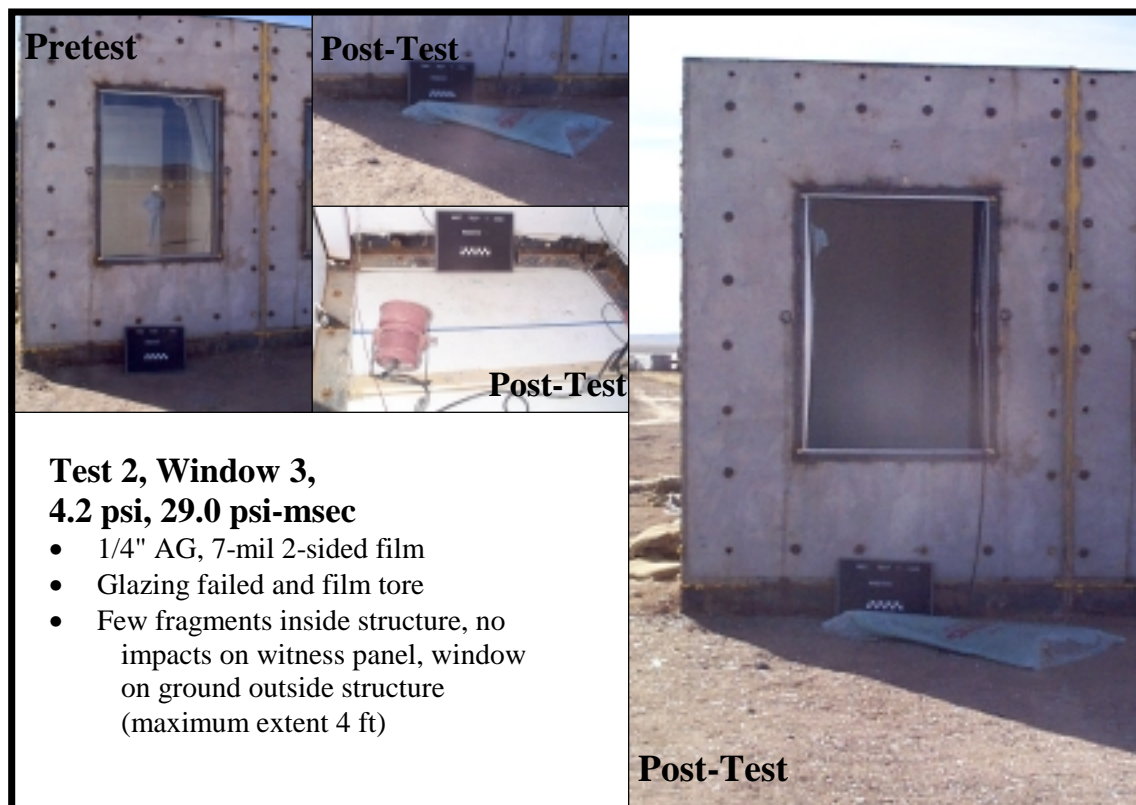
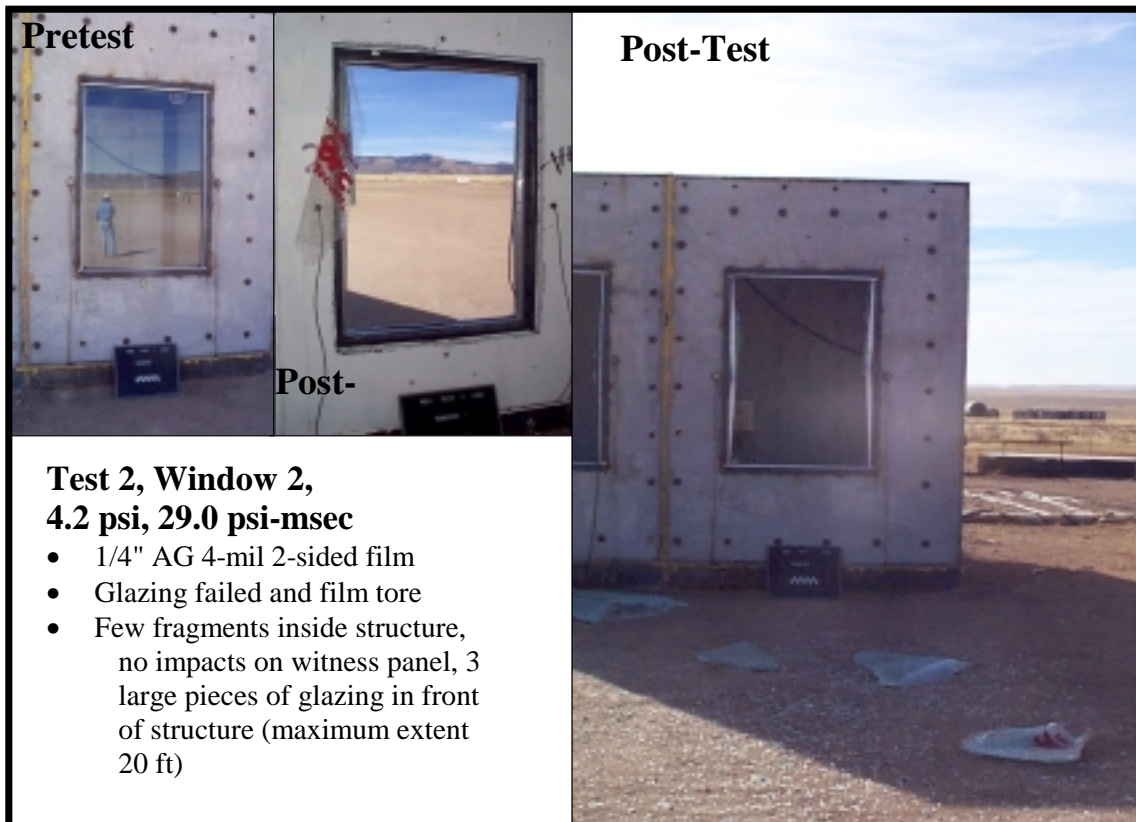


Table 4.2 presents results of test articles using two-sided mechanical attachment of film when subject to airblast loading of 4 psi (28 psi-msec). Film was installed with the right and left side of the film anchored by a mechanical attachment. The film extended under the attachment and was secured to the frame by a metal batten and self tapping screws. Each of the following test articles passed the GSA Performance Criteria for Level C buildings (performance conditions 1 through 4 are acceptable).

| Peak Pressure (PSI) | Test Article | Film | Attachment Method | GSA Performance Condition |
|---------------------|--------------|---------------|--------------------|---------------------------|
| 4.2 | MSC-2-2 | 4-mil | 2-sided mechanical | 3b |
| 4.2 | MSC-2-3 | 7-mil | 2-sided mechanical | 3b |
| 4.2 | MSC-2-1 | 8-mil, 2 ply | 2-sided mechanical | 3b |
| 4.2 | MSC-2-4 | 14-mil, 3 ply | 2-sided mechanical | 3b |

Table 4.2 Summary results for film with 2-sided mechanical attachment at 4 psi, 28 psi-msec pressure on ¼ inch annealed glass (46 × 64 inch window panes).



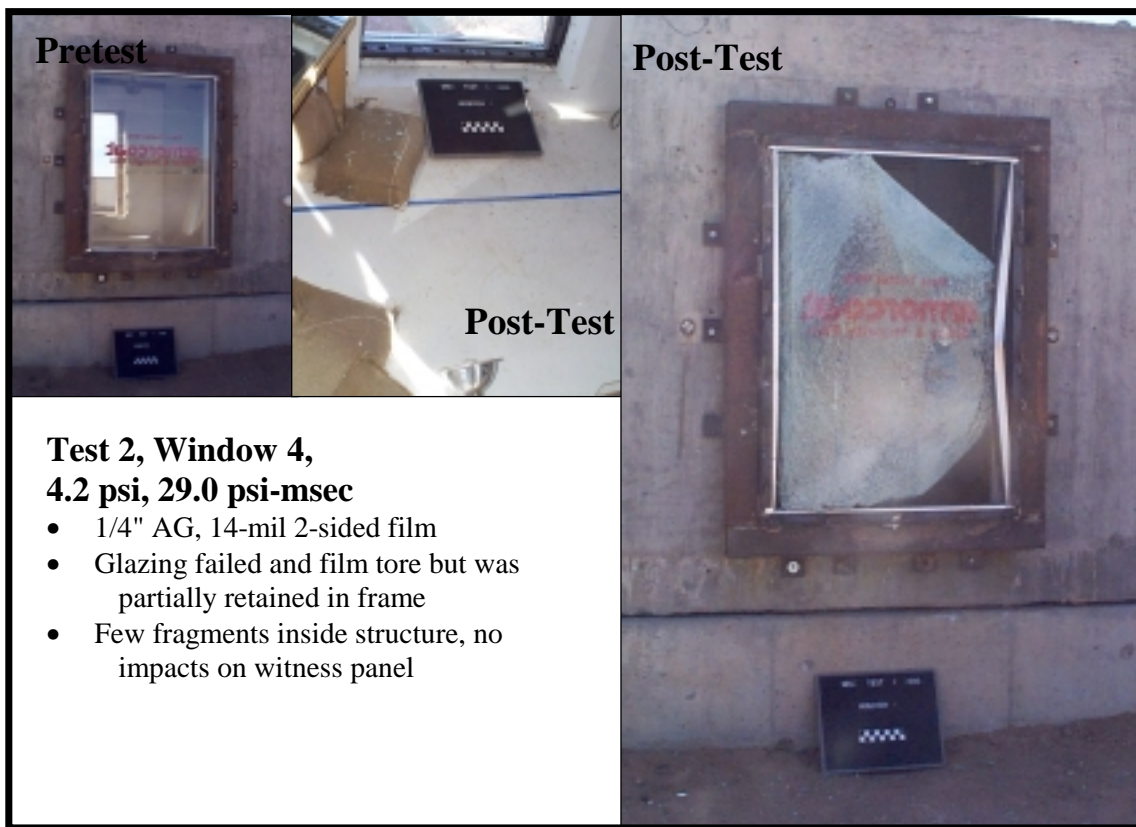
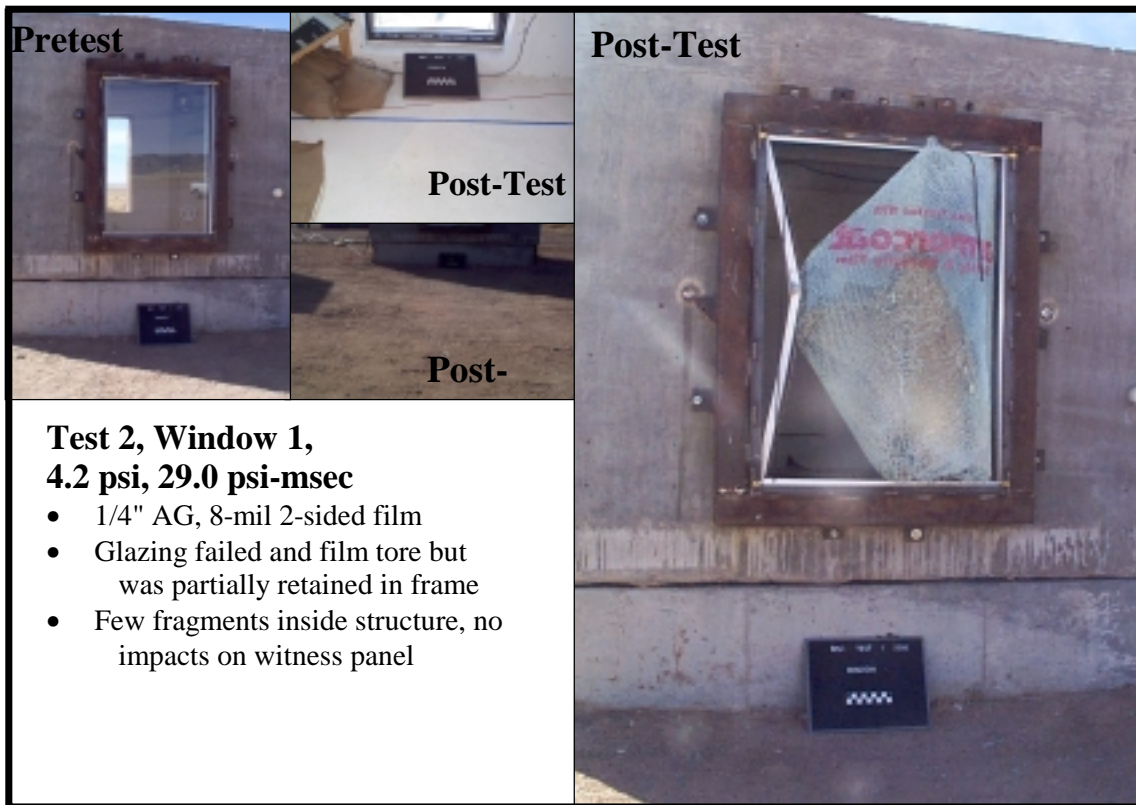


Table 4.3 presents results of test articles using four-sided mechanical attachment of film or a four-sided wet glaze attachment when subject to airblast loading of 4 psi. In the four-sided attachment, film was installed with the film anchored by a mechanical attachment on each side of the window frame. The film extended under the attachment and was secured to the frame by a metal batten and self tapping screws. In the wet-glazed installation, the film was installed as a daylight application and then ½ inch of the film surface was secured to ½ inch of the frame (excluding the glazing bead) using a bead of Dow-Corning 995 structural silicone adhesive in a chamfered application. Each of the following test articles passed the GSA Performance Criteria for Level C buildings (conditions 1 through 4 are acceptable).

| Peak Pressure (PSI) | Test Article | Film | Attachment Method | GSA Performance Condition |
|---------------------|--------------|--------------|--------------------|---------------------------|
| 4.4 | MSC-3-1 | 8-mil, 2-ply | 4-sided mechanical | 3a |
| 4.4 | MSC-3-4 | 8-mil, 2-ply | Wet Glazed | 3a |

Table 4.3 Summary of results for film with four-sided mechanical attachment or four-sided wet glaze at 4 psi (28 psi-msec) on ¼ inch annealed glass (46 × 64 inch window panes).

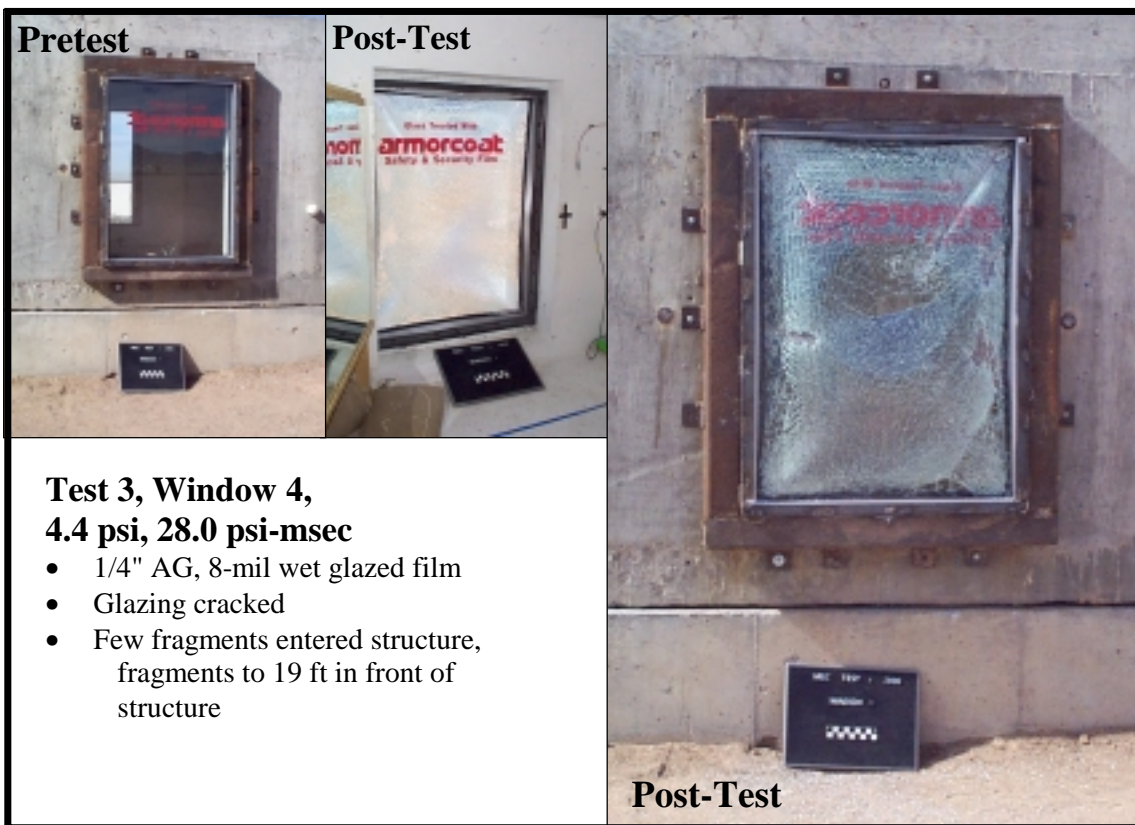
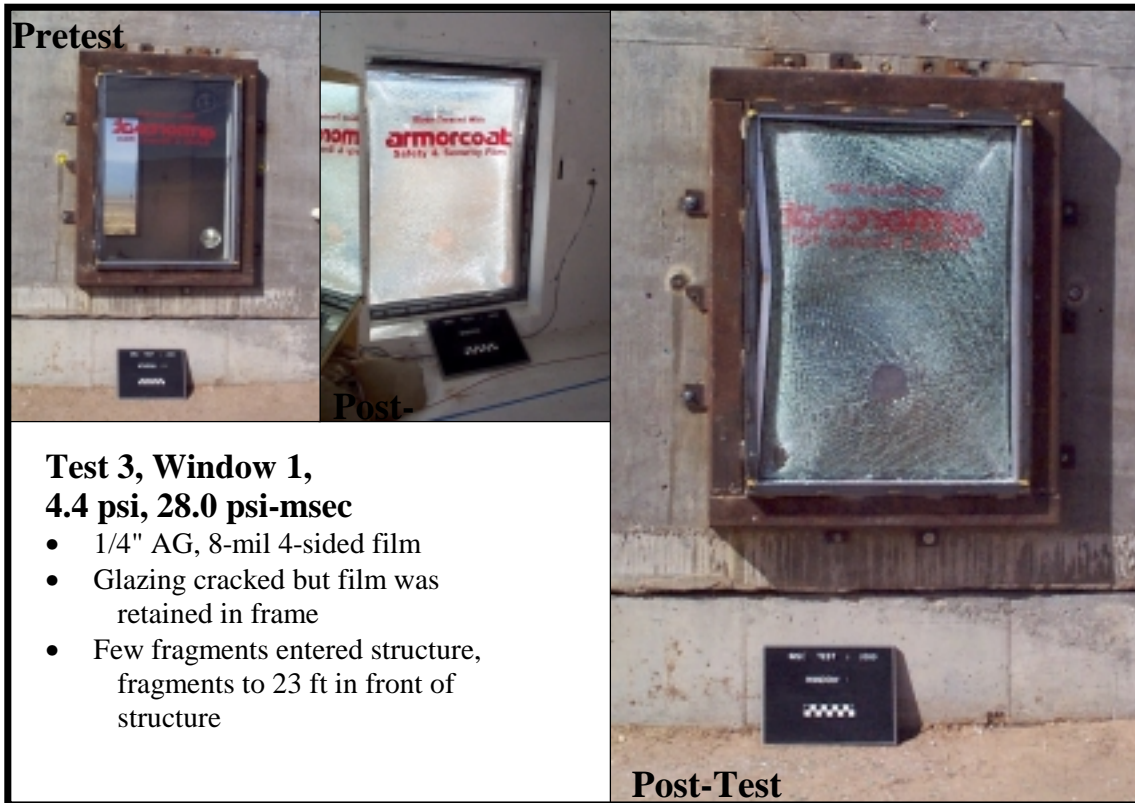
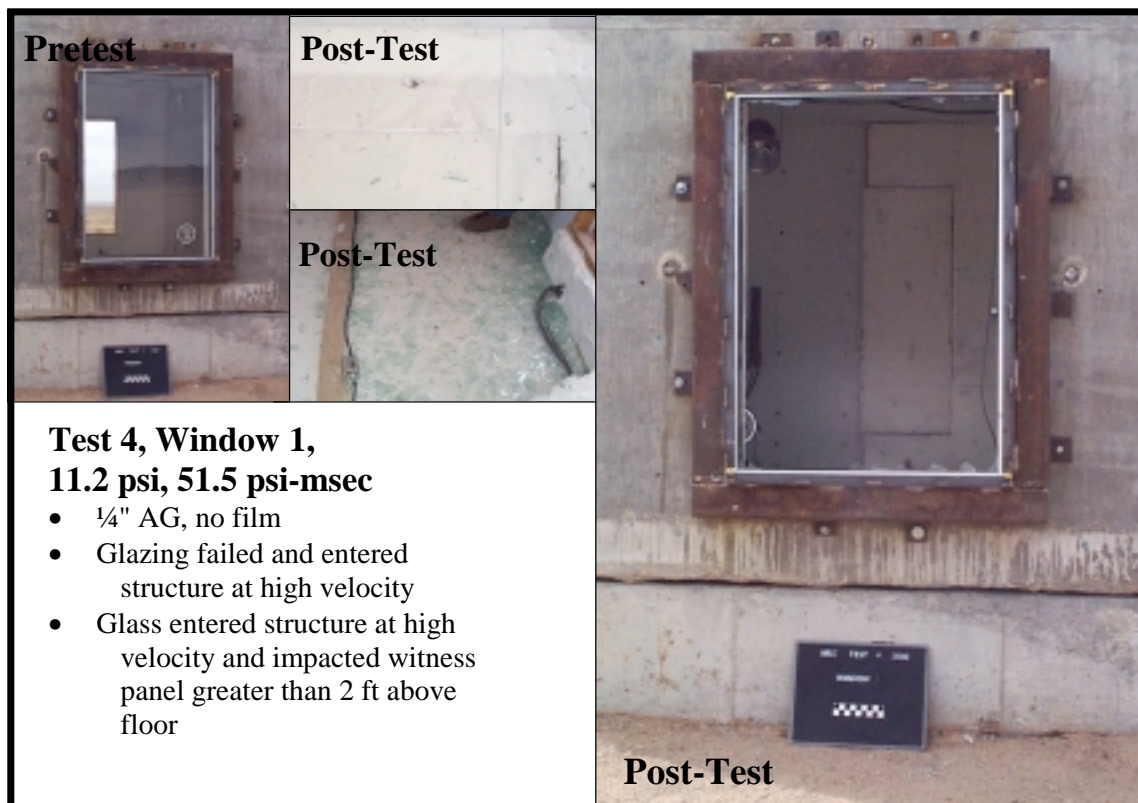


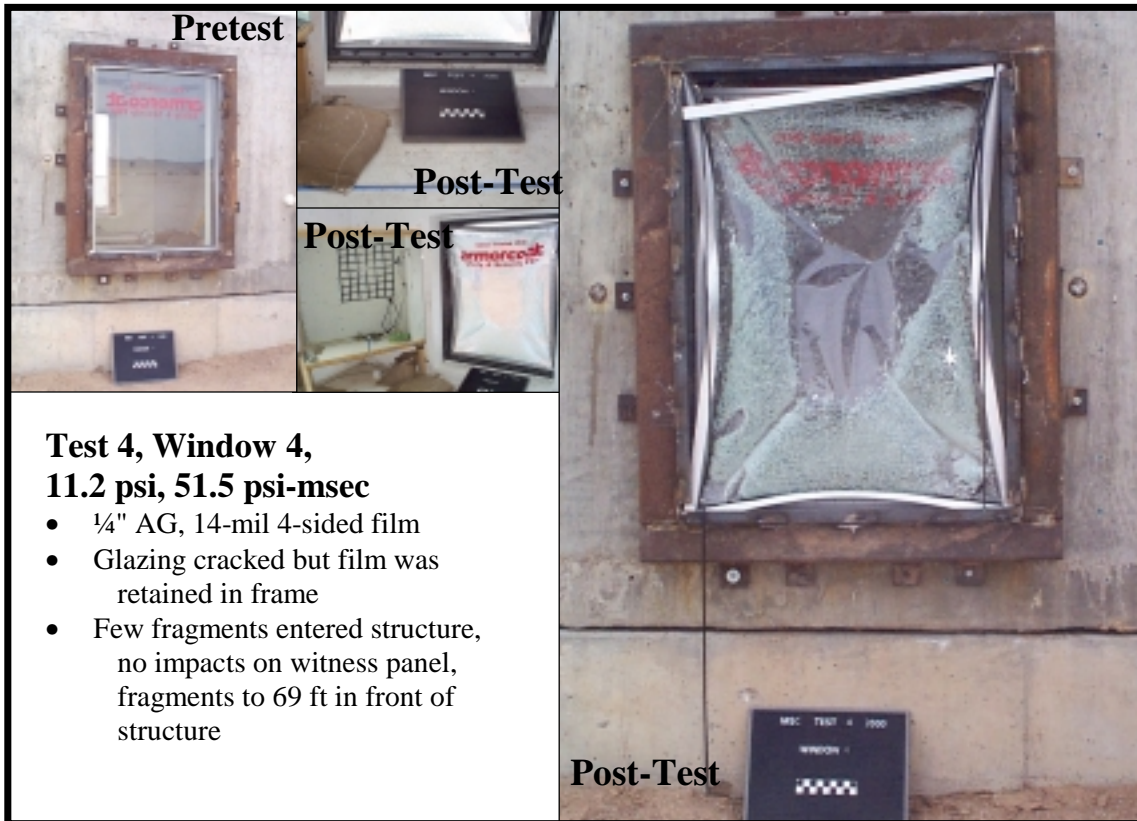
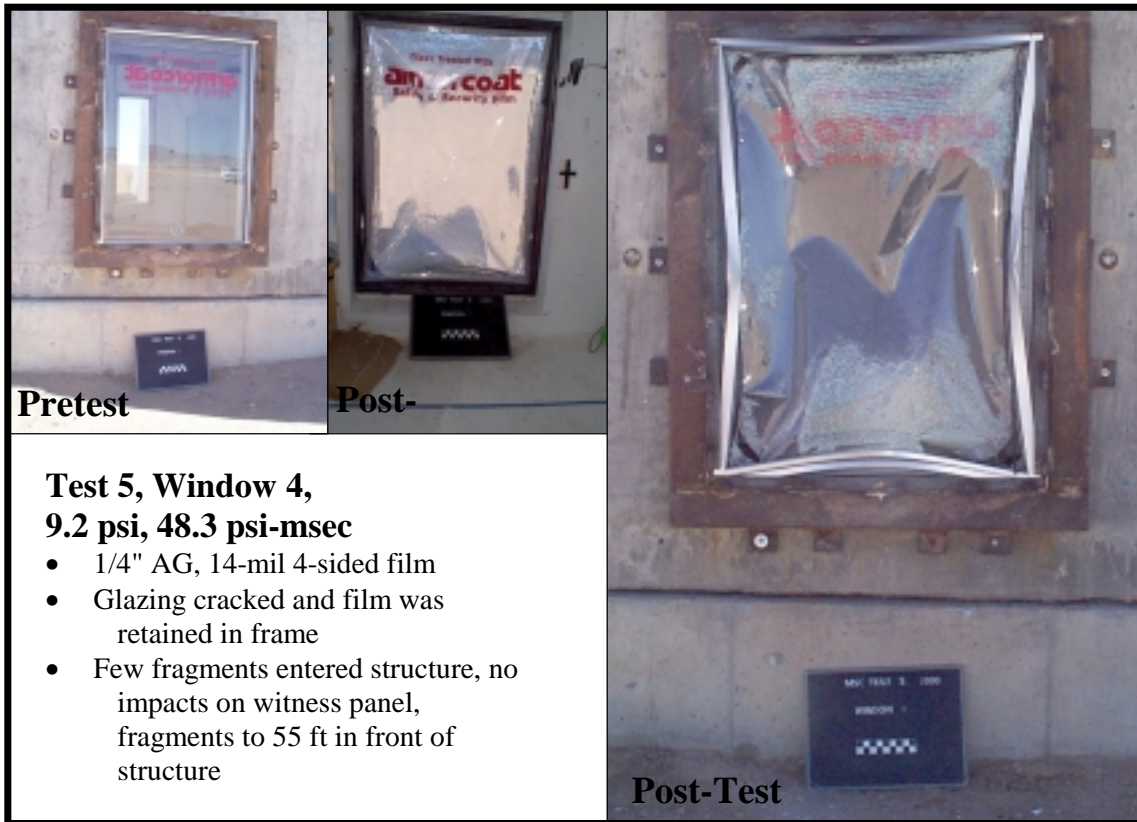
Table 4.4 presents the results of test articles when subjected to airblast loading of 10 psi and 48.3 psi-msec when using four-sided mechanical attachment.

Note: Although reflected pressure is per GSA Level D criteria, nominally, the measured impulse was 48.3 psi-msec not the full 89 psi-msec listed in the criteria.

| Peak Pressure | Test Article | Film | Attachment Method | GSA Performance Condition |
|---------------|--------------|---------------|--------------------|---------------------------|
| 11.2 | MSC-4-1 | No Film | --- | 5 |
| 9.2 | MSC-5-4 | 14-mil, 3-ply | 4-sided mechanical | 3a |
| 11.2 | MSC-4-4 | 14-mil, 3-ply | 4-sided mechanical | 3b |

Table 4.4 Summary of results for film with four-sided mechanical attachment or four-sided wet glaze at 10 psi pressure on ¼ inch annealed glass (46 × 64 inch window panes).





Conclusions

Of the window frame, film and attachment systems tested, several different systems met the GSA Performance Criteria for Level C Buildings. Testing included in this report indicates that even the 4-mil window films when properly installed can meet the GSA Level C criteria in a daylight application for the tested conditions. For higher loads, it is clear that heavier film and 4-sided attachment is required.

It is important to note the testing performed utilized standard ¼ inch annealed glass. In alternative glazing configurations (insulating glass, thicker glass, heat strengthened glass, thermally tempered glass, etc.), the results would differ. In fact, equivalent filmed systems may perform better. Any comparison with other testing should be done on comparable glazing configurations.

APPENDIX B

History and Need for GSA Testing

History and Need for GSA Testing

When an explosion is detonated in an urban environment, window breakage is typically widespread and can occur over several city blocks. The window glass fragments generated by such an event are either driven into the buildings or drawn outside the buildings resulting in injury to building occupants and street pedestrians. For example, over 500 people in Oklahoma City sustained injuries (many due to window glass failure) and required medical attention due to the bombing of the A.P. Murrah Building in 1995. Similarly, over 5000 people were injured during the bombing of the US Embassy in Kenya in 1998.

To reduce the window glass fragment hazard generated by blast, several technologies have emerged, including security window films, laminated glass, blast curtains, blast louvers, etc. Security films, which are applied to the inner surface of the glazing, hold the glass together and use the plastic membrane response of the film to control the failure of the glazing. Blast testing has been performed on security window films, and they have been shown to be effective at reducing hazards associated with failed glazing.

The US General Services Administration (GSA) oversees design and construction of new facilities and manages the existing real property inventory for a large portion of the US Government. After the Oklahoma City bombing, the President issued a directive for government agencies to take action toward protecting government facilities. In response to this Presidential directive, the GSA published a security criteria document (GSA Security Criteria, Final Working Version, January 17, 1997 and subsequent revisions), which specifically addresses blast protection issues for both new and existing GSA facilities. Part of the criteria addresses window glazings and the associated hazard generated by blast. This portion of the criteria was based in part on a series of blast tests on windows performed by the GSA and other blast test data. The glazing criteria are performance based. The glass fragment hazard generated by windows is graded based on the post-blast location of glass fragments in a blast test. The GSA has indicated that manufacturers of glass fragment mitigating products must test their products to be considered for use in GSA Level C and D facilities.

MSC Specialty Films Inc. commissioned ARA to perform a series of five high-explosive blast tests in order to evaluate the performance of security window film products. The test data collected in this effort will provide useful information for many other government and civilian

entities, both domestic and foreign, that are responsible for security planning of building facilities.

The explosive tests were conducted at the Defense Threat Reduction Agency's Chestnut Test Site on Kirtland Air Force Base in New Mexico during the period of February 15-March 3, 2000. The test procedure was designed in accordance with the procedure adopted by the GSA. The GSA test procedure is included in Appendix A. Each test used 600 lb of ANFO (500 lb of TNT). The window sizes were nominally 4 ft by 5-1/2 ft. The windows were mounted in enclosed concrete reaction structures for testing. The standoff distance to the charge was varied to affect particular blast pressure levels on the windows.

APPENDIX C

Conversion Factors (Non-SI to SI Units of Measurement)

CONVERSION FACTORS

(NON-SI TO SI UNITS OF MEASUREMENT)

Non-SI units of measurement used in the report can be converted to SI units as follows:

| Multiply: | By: | To Obtain: |
|------------------------------|-------------|----------------------------------|
| degrees (deg) | 0.01745329 | radians (rad) |
| miles (U.S. statute) | 1.609347 | kilometers (km) |
| feet (ft) | 0.3048 | meters (m) |
| inches (in) | 25.4 | millimeters (mm) |
| mil | 0.0254 | millimeters (mm) |
| pounds (lb) | 4.448222 | newtons (N) |
| pounds (lb) | 0.4535924 | kilogram (kg) |
| kips per square inch (ksi) | 6.894757 | megapascals (mPa) |
| pounds per square inch (psi) | 6894.757 | pascals (N/m ² or Pa) |
| pounds per square inch (psi) | 6.894757 | kilopascals (kPa) |
| pounds per square inch (psi) | 0.006894757 | megapascals (mPa) |